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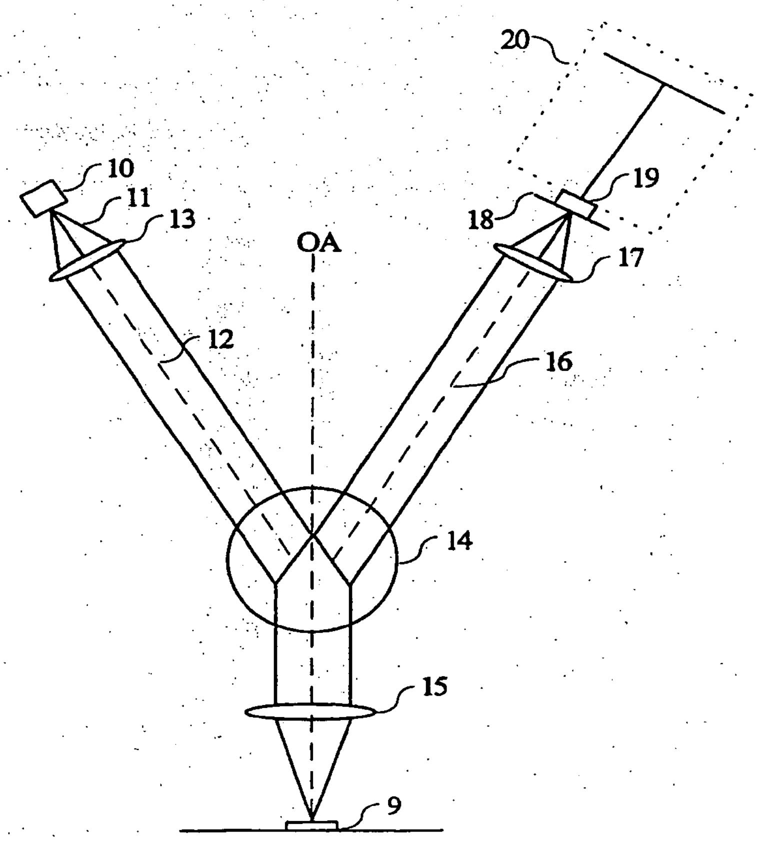
(54) Title: APPARATUS AND METHOD FOR SECONDARY ELECTRON EMISSION MICROSCOPE

(57) Abstract

An apparatus and method for inspecting a surface of a sample (S), particularly but not limited to a semiconductor device, using an electron beam presented. The technique is called Secondary Electron Emission Microscopy (SEEM), and has significant advantages over both Scanning Electron Microscopy (SEM) and Low Energy Electron Microscopy (LEEM) techniques. In particular, the SEEM technique utilizes a beam of relatively high-energy primary electrons (11) having a beam width approximate for parallel, multi-pixel imaging. The electron energy is near a charge-stable condition to achieve faster imaging than was previously attainable with SEM, and charge neutrality unattainable with LEEM.



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APPARATUS AND METHOD FOR SECONDARY ELECTRON EMISSION MICROSCOPE

BACKGROUND OF THE INVENTION

Technical Field

The present invention relates generally to an apparatus and a method for using electron beams to microscopically inspect the surface of an object, and more particularly to inspect layers in a semiconductor device.

Discussion of the Prior Art

A variety of methods have been used to examine microscopic surface structures of semiconductors. These have important applications in the field of semiconductor chip fabrication, where microscopic defects at a surface layer make the difference between a good or bad chip. Holes or vias in an intermediate insulating layer often provide a physical conduit for an electrical connection between two outer conducting layers. If one of these holes or vias becomes clogged, it will be impossible to establish this electrical connection and the whole chip may fail. Examination of the microscopic defects in the surface of the semiconductor layers is necessary to ensure quality control of the chips.

Electron beams have several advantages over other mechanisms to examine samples. Light beams have an inherent resolution limit of about 100 nm – 200 nm, but electron beams can investigate feature sizes as small as a few nanometers. Electron beams are manipulated fairly easily with electrostatic and electromagnetic elements, and are certainly to produce and manipulate than x-rays.

Electron beams in semiconductor defect inspection do not produce as many false positives as optical beams. Optical beams are sensitive to problems of color noise and grain structures whereas electron beams are not. Oxide trenches and polysilicon lines are especially prone to false positives with optical beams due to grain structure.

A variety of approaches involving electron beams have been utilized for examining surface structure. In low-voltage scanning electron microscopy

(SEM), a narrow beam of primary electrons is raster-scanned across the surface of sample. Primary electrons in the scanning beam cause the sample surface to emit secondary electrons. Because the primary electrons in the beam of scanning electron microscopy are near a particular known electron energy (called 'E_2'), there is no corresponding charge build-up problem in SEM, and the surface of the sample remains neutral. However, raster scanning a surface with scanning electron microscopy is slow because each pixel on the surface is collected sequentially. Moreover, a complex and expensive electron beam steering system is needed to control the beam pattern.

Another approach is called Photo-Electron Emission Microscopy (PEM or PEEM), in which photons are directed at the surface of a sample to be studied, and by the photoelectric effect, electrons are emitted from the surface. On an insulating surface, the emission of these electrons, however, produces a net positive charge on the sample surface since there is a net flux of electrons from the surface. The sample continues to charge positively until there are no emitted electrons, or electrical breakdown occurs. This charge build-up problem limits the utility of PEEM for imaging insulators.

Another method of examining surfaces with electron beams is known as Low Energy Electron Microscopy (LEEM), in which a relatively wide beam of low-energy electrons is directed to be incident upon the surface of the sample, and electrons reflected from the sample are detected. However, LEEM suffers from a similar charge build-up problem since electrons are directed at the sample surface, but not all of the electrons are energetic enough to leave the surface. In LEEM, negatively-charged electrons accumulate on the surface, which repels further electrons from striking the sample, resulting in distortions and shadowing of the surface.

Several prior art publications have discussed a variety of approaches using electron beams in microscopy, but none have determined how to do so with parallel imaging at the same time the charge build-up problem is eliminated. One of these approaches is described by Lee H. Veneklasen in "The Continuing Development of Low-Energy Electron Microscopy for Characterizing Surfaces," Review of Scientific Instruments, 63(12), December 1992, pages 5513 to 5532. Veneklasen notes generally that the LEEM

electron potential difference between the source and sample can be adjusted between zero and a few keV, but he does not recognize the charging problem or propose a solution to it. Habliston et al., in "Photoelectron Imaging of Cells: Photoconductivity Extends the Range of Applicability," Biophysical Journal, Volume 69, October 1995, pages 1615 to 1624, describe a method of reducing sample charging in photoelectron imaging with ultraviolet light.

Thus, there remains a need for a method utilizing electrons beams to investigate sample surfaces that eliminates the charge build-up problem and increases the speed of examining large sample surfaces.

SUMMARY OF THE INVENTION

The present invention provides an improved apparatus and method, called Secondary Electron Emission Microscopy (SEEM), for using electron beams to inspect samples with electron beam microscopy. The apparatus images a large number of pixels in parallel on a detector array, and thereby has the properties of being faster and lower in noise than conventional Scanning Electron Microscopes. Electron beam scanning systems are not required, and the electron beam current densities are not as high so that the probability of damaging sensitive samples is lessened.

The method of the invention comprises: providing a sample of a material having a characteristic energy value; directing an electron beam having a width appropriate for parallel multi-pixel imaging to be incident on the sample; and maintaining a stable electrostatic charge balance of the sample. (A 'pixel,' or picture element, is defined by the projected size of the image on an element of an electron detector.) One application of SEEM is the detection of defects in the manufacture of semiconductor devices. Another is for investigating other materials, including biological samples and tissues.

The present invention overcomes many of the problems associated with prior art approaches to using electron beams for investigating sample surface structures by combining certain features of the LEEM and SEM techniques. Compared to the conventional Scanning Electron Microscope method of raster scanning an object, the invention utilizes a relatively wide beam of electrons to parallel-image the object. Essentially, a relatively wide

beam of primary electrons is used as in LEEM, but the energies of these electrons are characteristic of those used in SEM. By operating the primary electron beam near energy E_2 at a stable point on the yield curve of the sample material, the present invention realizes the unexpected advantage of eliminating the problem of charge build up on the sample surface associated with LEEM. The charge build-up on the surface of the object is controlled by directing the electron beam onto the object surface at an electron energy where the number of emitted secondary electrons equals the number of incident primary electrons.

SEEM is much faster than SEM because SEEM does not scan a narrow beam across the sample, but instead directs a relatively wide beam of electrons at the surface. To put this in numerical perspective, the spot size of the scanning beam in Scanning Electron Microscopy (SEM) is typically about 5 nanometers to 100 nanometers ($5x10^{-9}$ meters to $100x10^{-9}$ meters). The spot size of the incident beam in Secondary Electron Emission Microscopy (SEEM) is about one millimeter to ten millimeters ($1x10^{-3}$ meters to $10x10^{-3}$ meters). Thus, the spot size in SEEM is on the order of ten thousand to one million times larger than in SEM. Accordingly, SEEM is able to look at a larger surface more rapidly than is possible in SEM.

The primary electron energies in SEEM are close to the E_2 point used in SEM, i.e. about 1-2 keV (one thousand electron volts). In LEEM, the primary electron energies are in the range of 0-100 eV below the E_1 point for the material. Thus, the surface charges negatively.

The comparative speed advantage in SEEM, i.e. the maximum pixel rate, is limited mainly by the 'dwell time' and the 'current density.' The minimum dwell time that a beam must spend looking at a given image is determined by the acceptable Signal-to-Noise ratio of the image. The maximum current density is determined by such practical considerations as available gun brightness and possible sample damage. Because the focused beam of primary electrons in SEM must scan the beam across the entire surface to be inspected, the maximum practical pixel rate in Scanning Electron Microscopy is less than or equal to 100 million pixels/second (100MHz). In Secondary Electron Emission Microscopy (SEEM), a large two-dimensional area of the sample is imaged in parallel without the need for

scanning. The maximum pixel rate in SEEM is greater than 800 million pixels/second (800 MHz). The dwell time of the beam in SEEM may correspondingly be much longer than in SEM, and this permits a much lower current density while still maintaining a high Signal-to-Noise ratio. Thus, SEEM has the capability of investigating more sensitive sample surface structures while requiring lower brightness electron beam sources.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates the basic configuration of the SEEM apparatus of the present invention;

Figure 2 is a graph of the relationship between the charge balance yield ratio and the primary electron energy;

Figure 3 is a chart comparing the SEEM technique of the invention to prior art electron beam inspection techniques;

Figures 4 illustrates the imaging method of SEM;

Figure 5 illustrates the imaging method of SEEM for comparison with Figure 4;

Figure 6(a) shows how the electron beam of SEEM detects a defect (an obstruction) in a via of an insulating layer;

Figure 6(b) shows how the electron beam of SEEM inspects metal lines connecting vias; and

Figure 7 shows how the electron beam of SEEM is used to study biological samples.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows the basic configuration for the Secondary Electron Emission Microscopy (SEEM) apparatus of the present invention. An electron gun source 10 emits a beam 11 of primary electrons e_1 along path 12. The electron beam 11 is collimated by electron lens 13 and continues along path 12. Magnetic beam separator 14 then bends the collimated electron beam 11 to be incident along electron optical axis OA normal to the surface to be inspected. Objective electron lens 15 focuses the primary electrons, e_1, into a beam having a spot size in the range 1-10 mm and an incident energy on the order of 1 keV on sample S.

Primary electrons e_1 incident on the sample S produce secondary electrons e_2 which travel back along the axis OA perpendicular to the inspection surface to objective electron lens 15, where they are recollimated. Magnetic beam separator 14 bends the electrons to travel along image path 16. The electron beam along image path 16 is focused by projection electron lens 17 to image plane 18, where there is an electron detector 19, which is a camera or preferably a time delay integrating (TDI) electron detector. The operation of an analogous TDI optical detector is disclosed in U.S. Patent No. 4,877,326 to *Chadwick et al*, which is incorporated herein by reference. The image information may be processed directly from a 'back thin' TDI electron detector 19, or the electron beam may be converted into a light beam and detected with an optional optical system 20 and a TDI optical detector.

While the size of the electron beam spot on the sample S is preferably about one to two millimeters, it is more generally in the range of 0.1 to 100 millimeters. The size of this beam at the sample and imaging planes is optionally variable with a zoom imaging system to control the resolution and rate of acquiring the image. In any event, to eliminate edge effects, the beam width should be larger than, and preferably at least twice the characteristic dimension of, the detector at the image plane.

Figure 2 is a graph showing the charge ratio versus primary electron energy characteristic of electron beam inspection techniques such as LEEM, SEM and SEEM. Yield ratio η is defined as the number of electrons emitted by the surface, e_2, divided by the number of electrons incident on the

surface, e_1. Yield ratio η thus defines the amount of charge build-up on the surface being inspected since there will be a net charge build-up whenever η does not equal unity. A yield ratio of greater than one implies that more electrons are being emitted than are incident, resulting in a net positive charge at the surface, and conversely a yield ratio of less than one indicates that more electrons are incident on the surface than are being emitted, resulting in a negative charge build-up.

Yield curve C indicates the experimentally-derived mathematical function that defines the yield ratio at various incident electron energies, E, for a typical sample substance. As shown in Figure 2, line L is the line of charge balance, $\eta = 1$, and there are only three points on yield curve C where charge balance is achieved, i.e. $e_2/e_1 = 1$. These three points are $E_0 = 0$, E_1, and E_2. (Energy $E_0 = 0$ is uninteresting for present purposes since it represents a situation where no electrons are incident on the sample.) In region I, between line L and yield curve C, there is an excess of negative charge since e_2 is greater than e_1. In region II, between line L and yield curve C, there is an excess of positive charge since e_1 is greater than e_2, i.e. more secondary electrons are emitted than primary electrons are incident. In region III, between line L and curve C, the charge build-up again becomes negative.

One can see from Figure 2 that on yield curve C there are only two significant points, E_1 and E_2, where there exists a charge balance. The problem is that only point E_2 is actually stable. That is, if the energy, E, of the primary electrons incident on the sample surface varies in either direction from E_1 by a small amount, say, ΔE_1, the charge balance is quickly lost. Charge balance η becomes increasingly negative or increasingly positive depending upon whether E_1 was approached from the $+\Delta E_1$ or $-\Delta E_1$ direction. Point E_1 is unstable because the slope of curve C is positive at this point. However, point E_2 is stable because the slope is negative there. Any variation in incident electron energy from E_2 in the direction of either $+\Delta E_2$ or $-\Delta E_2$ tends to return the beam energy to point E_2. The values of E_1 and E_2 have been experimentally determined for a variety of substances, such as silicon dioxide, aluminum, and polysilicon. While each substance has its

own characteristic yield curve C, the general shape of these yield curves is as shown.

Figure 2 illustrates graphically the problem with past techniques of electron beam inspection, and shows why the present SEEM technique provides unexpected advantages. Low Energy Electron Microscopy (LEEM) generally operated below E_1, with electron energies of 100 eV or less. Since point E_1 is unstable, LEEM suffered from the problem of charge build-up. Scanning Electron Microscopy (SEM) operated just below E_2, with electron energies in the range of 1-2 keV. Because point E_2 is stable, there was no problem with charge build-up in SEM, but SEM is slow precisely because it requires scanning. Prior to the present invention, it is believed that none had thought to drive the relatively wide beam of the LEEM parallel imaging system at energy E_2, as is recognized by the SEEM technique of the invention. The SEEM technique of the present invention is therefore the first recognition of the advantages of combining the parallel imaging of LEEM with the charge balance of SEM.

It is important to note that for purposes of Figure 2 the primary electron energy is to be measured at the surface of the sample S. The energy of the electrons focused by objective electron lens 15 is generally different than the energy of the electrons at the sample S, called the landing energy, and this landing energy is often not easy to predict. The landing energy may depend on factors such as the current density of the beam, the material of the sample and the electric field at the surface.

The landing energy of the primary electrons is chosen as approximately E_2, but generally somewhere below E_2 on yield curve C. Figure 2 shows that yield curve C has a relative maximum in region II at point M. Generally, one chooses a landing energy for the electrons between point M and the E_2 value on yield curve C. In the case where the sample S includes a plurality of materials, the E_2 value and yield curve C are different for each of the materials. When there are a plurality of materials in sample S, one chooses a landing energy below the E_2 values of each of the plurality of materials so that the landing energy is not in the more charging regions III for any of the materials.

Figure 3 is a chart summarizing the differences between, and advantages of, the four PEEM, LEEM, SEM and SEEM techniques. PEEM uses photons instead of primary electrons to produce emitted secondary electrons. PEEM suffers from the problem of positive charge build-up on insulating sample target materials because secondary electrons are being knocked off the sample surface by the photons, but no negatively charged particles replace these secondary electrons. The inspecting photon beam of PEEM can be wide, and parallel imaging can be achieved.

In Low Energy Electron Microscopy (LEEM), a wide beam of primary electrons is projected at the inspection surface, and parallel imaging can be achieved. These primary electrons are relatively low in energy, and the imaging method involves reflecting these low-energy electrons from the surface. Because only low energy electrons are incident, primary electrons are reflected but few secondary electrons are emitted. Also, the low energy implies a negative charge build-up because these electrons are not sufficiently energetic to escape the sample surface.

In Scanning Electron Microscopy (SEM), relatively slow raster scanning imaging must be utilized because the electron beam is focused to a narrow spot size. SEM, however, produces energetic primary source electrons incident at energy E_2, which is a stable point on the yield curve, so that charge-neutral operation is attained. Energetic primary electrons produce secondary electrons in SEM.

In the Secondary Electron Emission Microscopy (SEEM) technique of the present invention, a beam of energetic primary electrons is directed at the sample surface with an energy E_2. Because a relatively wide beam of primary electrons is introduced, parallel imaging becomes possible, which is significantly faster than SEM imaging. Moreover, since these primary electrons are incident with an energy E_2, the sample remains charge neutral. SEEM thus combines the most favorable attributes of LEEM and SEM.

Figures 4 and 5 comparatively illustrate the respective imaging methods of Scanning Electron Microscopy and Secondary Electron Emission Microscopy. In Figure 4, a Scanning Electron Microscope produces a beam 41 of electrons and directs them at the surface of sample 42 having a characteristic dimension D. Beam 41 has a width "w," which is in the range

of 5 to 100 nanometers (50-1000 Angstroms). This beam 41 is raster-scanned in a pattern represented by path 43 across the surface of sample 42. (The number of scan lines is greatly reduced for purposes of illustration.) In order to control the beam 41 so that it travels along raster path 43, it is preferred for the inspection system to include an electron beam steering apparatus for electromagnetically deflecting the electron beam 41.

Figure 5 shows parallel imaging in the Secondary Electron Emission Microscopy inspection technique of the present invention. Beam 54 is produced from an electron gun source, and beam 54 has a width "W," typically about one to two millimeters, at the surface of sample 55. Sample 55 has the characteristic dimension D, which is much greater than the width W of the electron beam. In SEEM, the width of the electron beam 54 is much larger than in SEM, but it may still be possibly necessary to move the sample 55 with respect to the beam to scan the sample 55. However, in the preferred embodiment, SEEM requires only mechanical movement of the stage of the sample 55 with respect to beam 54, and not an electron beam deflection system for electromagnetically steering beam 41. The SEEM inspection system of the present invention can operate much faster than the SEM inspection system because SEEM images thousands or millions of pixels in parallel.

Figure 5 further shows a magnified view of the imaging portion of the beam 54 on the sample 55 to illustrate the parallel, multi-pixel imaging region 56 within beam 54. A rectangular detector array region 56 occupies a central portion of the beam 54 and defines the imaging aperture. (The detector array is either of the time delay integrating (TDI) or non-integrating type.) The detector array 56 images between about 500 thousand and one million pixels in parallel.

SEEM is therefore 500 thousand to one million times faster than SEM due to the number of pixels in the detector array. If SEEM spends one millisecond looking at a pixel, SEM can only take one or two nanoseconds for that pixel to capture the same data frame at 100 MHz. Accordingly, the current density at the sample surface in SEEM is 10^6 (i.e. one million) times smaller than in SEM, which results in less damage to the sample. If, say, that 10,000 electrons per pixel are required for a good image, SEM must

pour a larger number of electrons per unit time onto the pixel spot. In SEEM, the same number of electrons are spread out over a longer time because one million pixels are imaged simultaneously.

It further follows that SEEM has better noise reduction characteristics than SEM. At 100 MHz, SEM samples each pixel for one nanosecond while SEEM spends one millisecond looking at each pixel. SEEM, therefore, averages out noise above one kHz, while SEM can only average out noise above 100 MHz. In defect detection applications, this implies fewer false positives and a better signal-to-noise ratio.

SEEM obtains additional advantages in charge control by flooding the sample 55 with beam 54, but imaging only the central portion of the beam 54 to eliminate edge effects. Ordinarily, non-uniformities in charge on the imaging surface lead to imaging distortions by deflecting the beam. The sample surfaces at the edge of the beam 54 have less uniform charge distributions than the surfaces at the interior portion of the beam because there is no electron flux outside the circumference of the beam diameter. There are further edge effects because of the residual charging in areas the beam has already scanned. By flooding an area 54 larger than the imaging area of the detector array region 56, these imaging distortions are avoided. In SEM, edge effects cannot be eliminated by this method because the beam diameter is too small for further aperturing. Techniques for reducing the effect of surface charge accumulation are taught in U.S. Patent No. 5,302,828 to *Monahan*, which is hereby incorporated by reference.

The present invention optionally may include additional means for maintaining the charge balance at the sample. While the electron beam energy is generally chosen to approximately maintain this charge balance, in actual practice solely controlling the electron beam energy may not be sufficient. One possibility is to apply a supplemental electric field by attaching electrodes to the sample. A variable voltage control feeds current to the electrodes thereby supplying an additional degree of freedom towards charge balance stability. Another possibility is to introduce a low pressure gas, such as argon, into the vacuum chamber which contains the sample to control the charge balance. The low pressure gas may act to prevent the accumulation of excess charge on the sample. While the above techniques

are exemplary of additional control means for maintaining the charge stability of the sample, they are by no means all-inclusive, and other such techniques may exist or be subsequently discovered to regulate charge control.

Any of these additional charge control means optionally may be utilized with the flooding method of *Monahan, supra.* The use of an electron beam of a particular energy with respect with the E_2 value of the material acts as a first order approximation to maintaining a stable charge balance. The use of additional charge control means such as flooding, electrodes, and/or low pressure gas acts a second order approximation to maintaining this charge balance. The combination of these first and second order charge control means may optionally be required for a practical charge control apparatus.

It is useful to compare the limitations imposed by the maximum scan rate in SEEM and SEM. To summarize the advantages of SEEM over SEM:

(1) Lower Noise. A longer image integration time is obtained for a given sample area. Averaging over longer sampling times results in less noise.

(2) Less Image Distortion. By flooding a larger area on the sample than is imaged, a more uniform charge distribution is maintained for the imaged area, and edge effect distortion is eliminated.

(3) Lower Current Densities. Lower current densities, made possible by parallel imaging and greater dwell times, imply that there is a reduced probability of damage to the sample.

(4) Faster. Parallel imaging means that many pixels (e.g. one million) are imaged at the same time in SEEM. Only one pixel is imaged at one time in SEM.

(5) No High Speed Scanning Electronics. These scanning systems are complex and expensive, but are not required in SEEM because of faster parallel imaging.

Figure 6(a) illustrates how an electron beam of the present invention detects defects in a via between the layers of a semiconductor device. An intermediate stage of fabrication of semiconductor device 60 is shown. In this example, semiconductor device 60 consists of a substrate 61, a metal layer 62 deposited on substrate 61, and an insulating layer 63 formed over

metal layer 62. Vias or holes 64, 65 are shown extending through insulating layer 63 to metal layer 62. At a subsequent stage of fabrication, a second metal layer 66 is formed over insulating layer 63, and vias 64, 65 are filled with an electrically conductive material to form electrical connections between metal layers 62 and 66. At the present stage of fabrication, however, metal layer 66 has not yet been deposited, so it is only shown in dotted lines. Generally speaking, vias 64 and 65 are formed by etching insulating layer 63. Via 64, however, is here shown to be clogged while via 65 is clear. Via 64 may, for example, become clogged with foreign material, or it may be clogged because of imperfections in the etching process. In either event, via 64 represents a defective via, while via 65 represents a perfect via.

Figure 6(a) further shows a beam 67 of primary electrons incident normal to the surface of semiconductor device 60 onto insulating layer 63. Because layer 63 is an insulating material, electron mobility on layer 63 is limited. Insulating layer 63 therefore has a tendency to collect charge on its surface, and this has led to the charge build-up problems associated with prior art inspection techniques such as LEEM. However, in the Secondary Electron Emission Microscopy (SEEM) technique of the present invention, the energy of the electrons in beam 67 is chosen to be sufficiently near the E_2 value of the material of insulating layer 63. Thus, upon illumination by primary electron beam 67, a secondary electron beam 68 is produced by insulating material 63 with minimal build-up of charge on surface 63 of the material. Secondary electron beam 68 is emitted in a direction normal to the surface of insulating layer 63, and in a sense opposite to primary electron beam 67. Secondary electron beam 68 contains information about the defective and perfect vias 64, 65, and this information passes back through the optical system, is detected and subsequently processed to enable the operator to determine whether the semiconductor device 60 is defective.

Figure 6(b) shows electron beam inspection of the semiconductor device 60 of Figure 6(a) at a subsequent stage of construction. Metal lines 66a and 66b extend in a direction perpendicular to the page to connect metal layer 62 through vias 64, 65, thereby providing electrical contact between lines 66a, 66b and layer 62. Primary electron beam 67 is incident

on semiconductor device 60, and particularly on metal lines 66a, 66b and insulating layer 63. Inspective imaging of the surface of metal lines 66a, 66b and insulating layer 63 is achieved with the charge differential information encoded on secondary electron beam 68.

Process control monitoring for the semiconductor industry is thereby improved with electron beam inspection of the present invention as compared with optical beam inspection by reducing or eliminating false positives due to grain structures and color noise. Once a defect has been identified, it may be repaired with a procedure such as focused ion beam implantation if the defect is critical.

More generally, the secondary electron emission microscope of the present invention is used to inspect defects in any semiconductor device, thin film magnetic head, reticle for semiconductor fabrication or flat panel (e.g., liquid crystal or field effect) display. Insulating, semiconducting, or conducting materials, or even superconductors and plasmas, are capable of being imaged with SEEM. A typical semiconductor fabrication process involves ultraviolet reduction projection of a reticle pattern produced for a wafer design, followed by chemical etching for each of the device layers. Alternatively, semiconductor devices are patterned with ion beams or etching, or by other CMP processing. Process inspection and monitoring of the intermediate and final products is then performed with the method of the present invention.

Figure 7 illustrates how the Secondary Electron Emission Microscope (SEEM) of the present invention is applied to studying a biological sample 70 on a stage carrier 77. Biological sample 70 has various features 71, 72, 73, and 74. For example, sample 70 may be a cell including a cell wall 71, a cell nucleus 72, protoplasm 73 and mitochondrion 74. Or, sample 70 may be human tissue including muscle 71, bone 72, fluid 73 and malignant cells 74. A beam 75 of primary electrons is incident normally on sample 70. Beam 75 has a landing energy just below the mean E_2 values characteristic of the materials of cell 70 in order to prevent charge build-up on cell 70. A beam 76 of secondary electrons is produced upon illumination of cell 70 with beam 75, and beam 76 passes normally back through the electron optical system.

Information about cell 70 is encoded in beam 76, and is detected and processed to obtain information about cell 70.

While the present invention has been described above in general terms, it is to be understood that the apparatus and method of the present invention could be adapted to a variety of applications. Accordingly, it is intended that the present invention cover all such adaptations, alterations, modifications and other applications as fall within the scope of the following claims.

We claim:

1. A method for using electron beams to inspect objects, comprising:
providing a sample of a material having a characteristic energy value;
directing an electron beam having a width appropriate for parallel multi-pixel imaging to be incident on said sample; and
maintaining a stable electrostatic charge balance of said sample.

2 The method of claim 1, wherein:
said directing step uses said electron beam having an energy less than or approximately equal to the characteristic energy value of said material.

3. The method of claim 2, wherein:
said directing step uses said electron beam with an energy greater than the maximum point of a yield curve for said material.

4. The method of claim 1, wherein:
said sample comprises two or more materials, and said beam has an energy near the characteristic energy value of said sample.

5. The method of claim 1, said directing step further comprising:
collimating said electron beam and focusing said electron beam at said sample.

6. The method of claim 1 further comprising:
detecting an image pattern of a secondary electron beam from said sample at an image plane.

7. The method of claim 6, said directing step further comprising:
collimating and focusing said secondary electron beam at said image plane.

8. The method of claim 6, wherein:

said step of directing includes directing primary electrons at said sample; and

said step of detecting includes detecting secondary electrons produced by said sample.

9. The method of claim 1, wherein said sample comprises an insulating material.

10. The method of claim 1, wherein said sample comprises a semiconducting material.

11. The method of claim 1, wherein said sample comprises a conducting material.

12. The method of claim 1, wherein:

said sample comprises a semiconductor wafer that is process monitored.

13. The method of claim 1, wherein:

said sample comprises a thin film magnetic material that is process monitored.

14. The method of claim 1, wherein:

said sample comprises a reticle that is process monitored.

15. The method of claim 1, wherein:

said sample comprises a flat panel display that is process monitored.

16. The method of claim 1, wherein said sample comprises a biological material.

17. The method of claim 1, wherein:
said electron beam has an energy in the range of one to two keV measured at a surface of said sample.

18. The method of claim 1, wherein said beam width is larger than a projected size of a detector.

19. The method of claim 1, wherein:
said beam width is in the range of 0.1 to 100 millimeters.

20. The method of claim 1 further comprising:
varying the magnification of a sample image to change the resolution and rate of acquiring said image.

21. The method of claim 1 further comprising:
providing additional controls to maintain said electrostatic charge balance.

22. The method of claim 1 wherein:
said electrostatic charge balance is maintained by making said characteristic energy value of said material equal to an electron beam energy of said electron beam.

23. The method of claim 1 wherein:
said electrostatic charge balance is maintained by making said characteristic energy value of said material equal to an electron beam energy of said electron beam with additional charge control means.

24. An apparatus for using electron beams to inspect objects, comprising:

a sample of a material having a characteristic energy value; and

a source of an electron beam having a width appropriate for parallel multi-pixel imaging directed on said sample;

wherein a stable electrostatic charge balance of said sample is maintained.

25. The apparatus of claim 24, wherein:

said electron beam has an energy less than or approximately equal to the characteristic energy value of said material.

26. The apparatus of claim 25, wherein:

said energy is greater than the maximum point of a yield curve for said material.

27. The apparatus of claim 24, wherein:

said sample comprises two or more materials, and said beam has an energy near the characteristic energy value of said sample.

28. The apparatus of claim 24, further comprising:

an electron collimating lens for collimating said electron beam and an electron focusing lens for focusing said electron beam.

29. The apparatus claim 24, further comprising:

an electron detector for detecting an image pattern of said electron beam at an image plane.

30. The apparatus of claim 24, further comprising:

an electron collimating lens for collimating, and an electron focusing lens for focusing, said electron beam at said image plane.

31. The apparatus of claim 24, wherein:
primary electrons are directed at said sample; and
secondary electrons are produced by said sample and detected.

32. The apparatus of claim 24, wherein said sample comprises an insulating material.

33. The apparatus of claim 24, wherein said sample comprises a semiconducting material.

34. The apparatus of claim 24, wherein said sample comprises a conducting material.

35. The apparatus of claim 24, wherein:
said sample comprises a semiconductor wafer that is process monitored.

36. The apparatus of claim 24, wherein said sample comprises a thin film magnetic material that is process monitored.

37. The apparatus of claim 24, wherein said sample comprises a reticle that is process monitored.

38. The apparatus of claim 24, wherein said sample comprises a flat panel display that is process monitored.

39. The apparatus of claim 24, wherein said sample comprises a biological material.

40. The apparatus of claim 24, wherein:
said electron beam has an energy in the range of one to two keV.

41. The apparatus of claim 24, wherein:
said beam width is greater than a projected size of a detector.

42. The apparatus of claim 41, wherein:
said beam width is in the range of 0.1 to 100 millimeters.

43. The apparatus of claim 24, further comprising:
additional controls for maintaining said charge balance.

44. The apparatus of claim 24 wherein:
said electrostatic charge balance is maintained by making said characteristic energy value of said material equal to an electron beam energy of said electron beam.

45. The apparatus of claim 24 wherein:
said electrostatic charge balance is maintained by making said characteristic energy value of said material equal to an electron beam energy of said electron beam with additional charge control means.

46. An apparatus for using electron beams to inspect objects, comprising:

a sample of a material having a characteristic energy value;

a primary electron beam having a width appropriate for parallel multi-pixel imaging incident on said sample;

an electron collimating lens for collimating said primary electron beam;

an electron objective lens for focusing said collimated beam at said sample and for collimating electrons produced by said sample into a secondary electron beam;

an electron focusing lens for focusing said collimated secondary electron beam at an image plane;

an electron detector for detecting an image pattern of said focused secondary electron beam at said image plane; and

an electron beam separator for redirecting said primary electron beam towards said electron objective lens and said secondary electron beam towards said electron focusing lens;

wherein a stable electrostatic charge balance is maintained at said sample.

47. An apparatus for inspecting objects with electron beams, comprising:

a sample of a material having a characteristic energy value;

electron beam source means for producing a primary electron beam having a width appropriate for parallel multi-pixel imaging incident on said sample;

electron collimating lens means for collimating said electron beam;

electron objective lens means for focusing said collimated electron beam at said sample and for collimating electrons produced by said sample into a secondary electron beam;

electron detector means for detecting an image pattern of said secondary electron beam at an image plane;

electron projection lens means for focusing said secondary electron beam on said electron detector means at said image plane; and

electron beam separator means for redirecting said primary electron beam towards said electron objective lens and redirecting said secondary electron beam towards said electron projection lens means;

wherein a stable electrostatic change balance of said sample is maintained.

48. An apparatus for using electron beams to inspect objects, comprising:

sample means of a material having a characteristic energy value;

electron beam means for directing an electron beam having a width appropriate for parallel multi-pixel imaging to be incident on said sample; and

means for maintaining a stable electrostatic charge balance of said sample.

49. The apparatus of claim 48, wherein:

said electron beam has an energy less than or approximately equal to the characteristic energy value of said material.

50. The apparatus of claim 49, wherein:

said energy is greater than the maximum point of a yield curve for said material.

51. The apparatus of claim 48, wherein:

said sample means comprises at least two materials, and said beam has an energy near the characteristic energy value of said sample means.

52. The apparatus of claim 48, further comprising:

electron collimating lens means for collimating said electron beam; and

electron focusing lens means for focusing said electron beam.

53. The apparatus claim 48, further comprising:

electron detector means for detecting an image pattern of said electron beam at an image plane.

54. The apparatus of claim 48, further comprising:

electron collimating lens means for collimating said electron beam and an electron focusing lens means for focusing said collimated electron beam at said image plane.

55. The apparatus of claim 48, wherein:

primary electrons are directed at said sample means; and

secondary electrons are produced by said sample means and are detected.

56. The apparatus of claim 48, wherein said sample means comprises an insulating material.

57. The apparatus of claim 48, wherein said sample means comprises a semiconducting material.

58. The apparatus of claim 48, wherein said sample means comprises a conducting material.

59. The apparatus of claim 48, wherein said sample means comprises a semiconductor wafer that is process monitored.

60. The apparatus of claim 48, wherein said sample means comprises a thin film magnetic material that is process monitored.

61. The apparatus of claim 48, wherein said sample means comprises a reticle that is process monitored.

62. The apparatus of claim 48, wherein said sample means comprises a flat panel display that is process monitored.

63. The apparatus of claim 48, wherein said sample means comprises a biological material.

64. The apparatus of claim 48, wherein:
said electron beam has an energy in the range of one to two keV.

65. The apparatus of claim 48, wherein:
said beam width is greater than a projected size of a detector.

66. The apparatus of claim 48, wherein:
said beam width is in the range of 0.1 to 100 millimeters.

67. The apparatus of claim 48, further comprising:
control means for additionally maintaining said charge balance.

68. The apparatus of claim 48 wherein:
said means for maintaining said electrostatic charge balance is achieved by making said characteristic energy value of said material equal to an electron beam energy of said electron beam.

69. The apparatus of claim 48 wherein:

said means for maintaining said electrostatic charge balance is achieved by making said characteristic energy value of said material equal to an electron beam energy of said electron beam with additional charge control means.

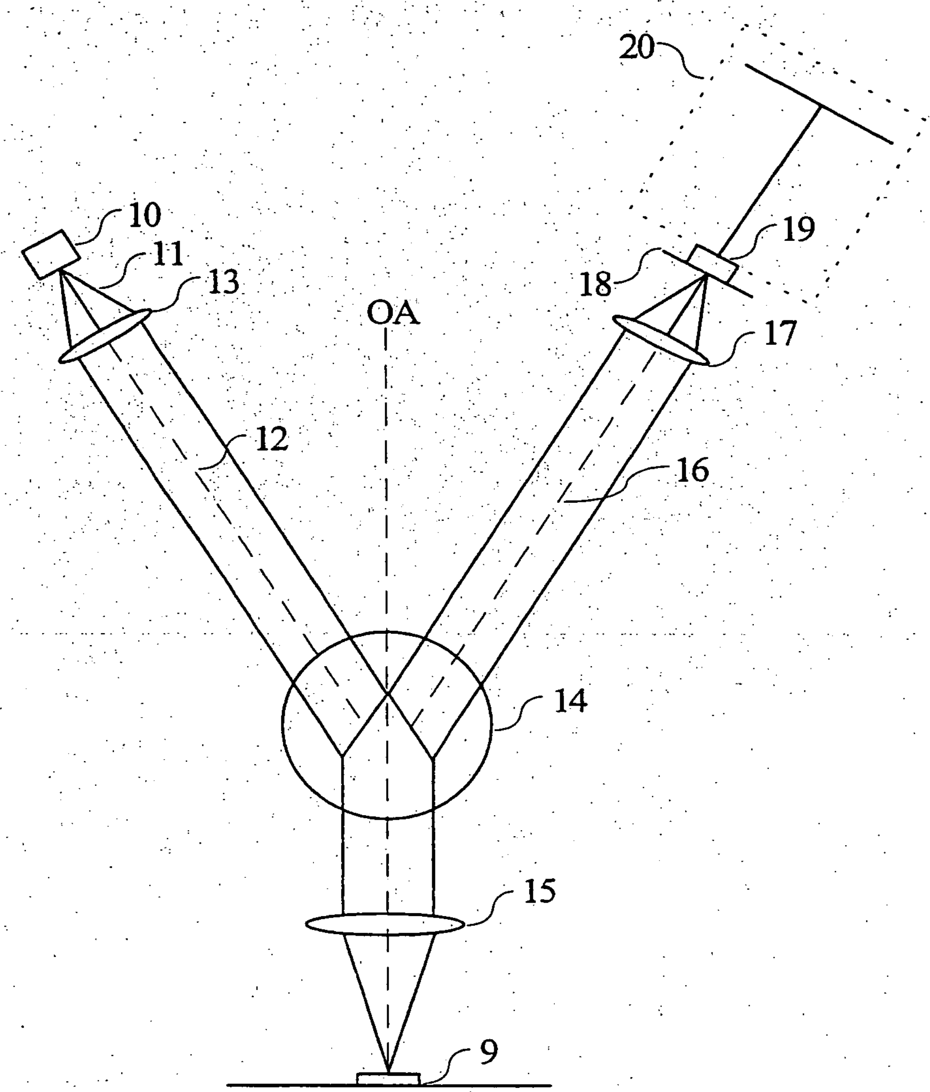

Figure 1

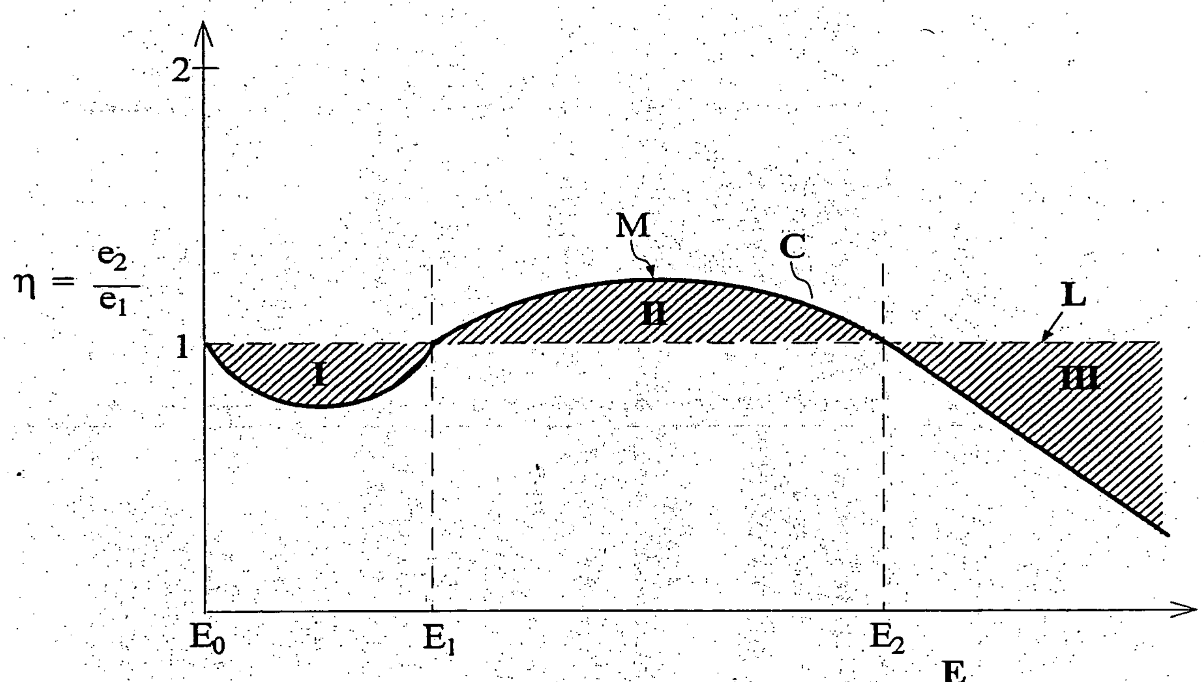

Figure 2

	PHOTO-ELECTRON EMISSION MICROSCOPY PEM	LOW ENERGY EMISSION MICROSCOPY LEEM	LOW VOLTAGE SCANNING ELECTRON MICROSCOPY SEM	SECONDARY ELECTRON EMISSION MICROSCOPY SEEM
INCIDENT PARTICLES	PHOTONS $h\nu=E_P >$ BINDING ENERGY	ELECTRONS (e_1) $0 < E_p < 100eV$	ELECTRONS	ELECTRONS
DETECTED PARTICLES	PHOTO-ELECTRONS (e_2)	REFLECTED ELECTRONS(e_1)	SECONDARY ELECTRONS (e_2)	SECONDARY ELECTRONS (e_2)
IMAGING METHOD	PARALLEL IMAGING	PARALLEL IMAGING	RASTER SCANNING	PARALLEL IMAGING
CHARGING	CHARGE BUILD-UP (+) POSITIVE	CHARGE BUILD-UP (-) NEGATIVE	LIMITED CHARGING	LIMITED CHARGING

Figure 3

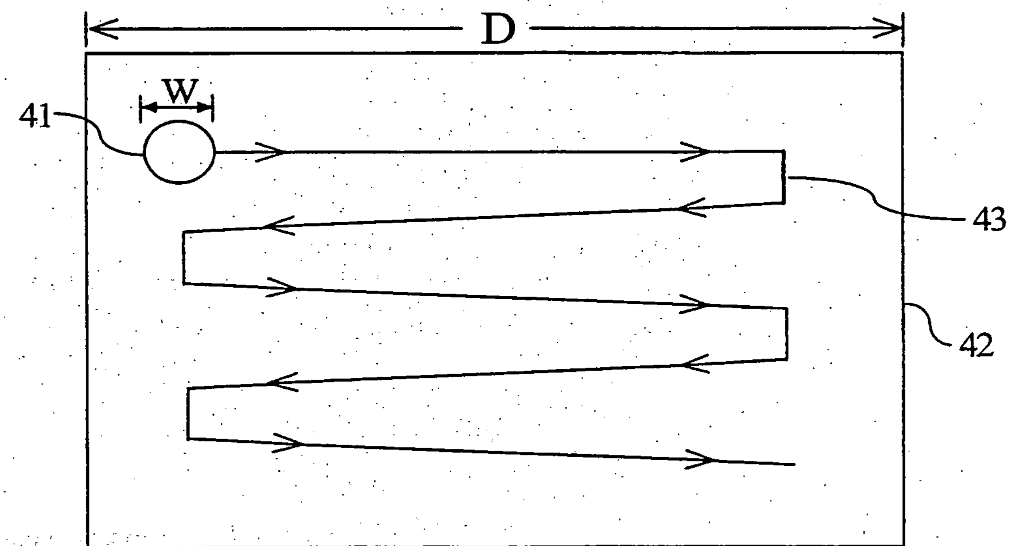

Figure 4

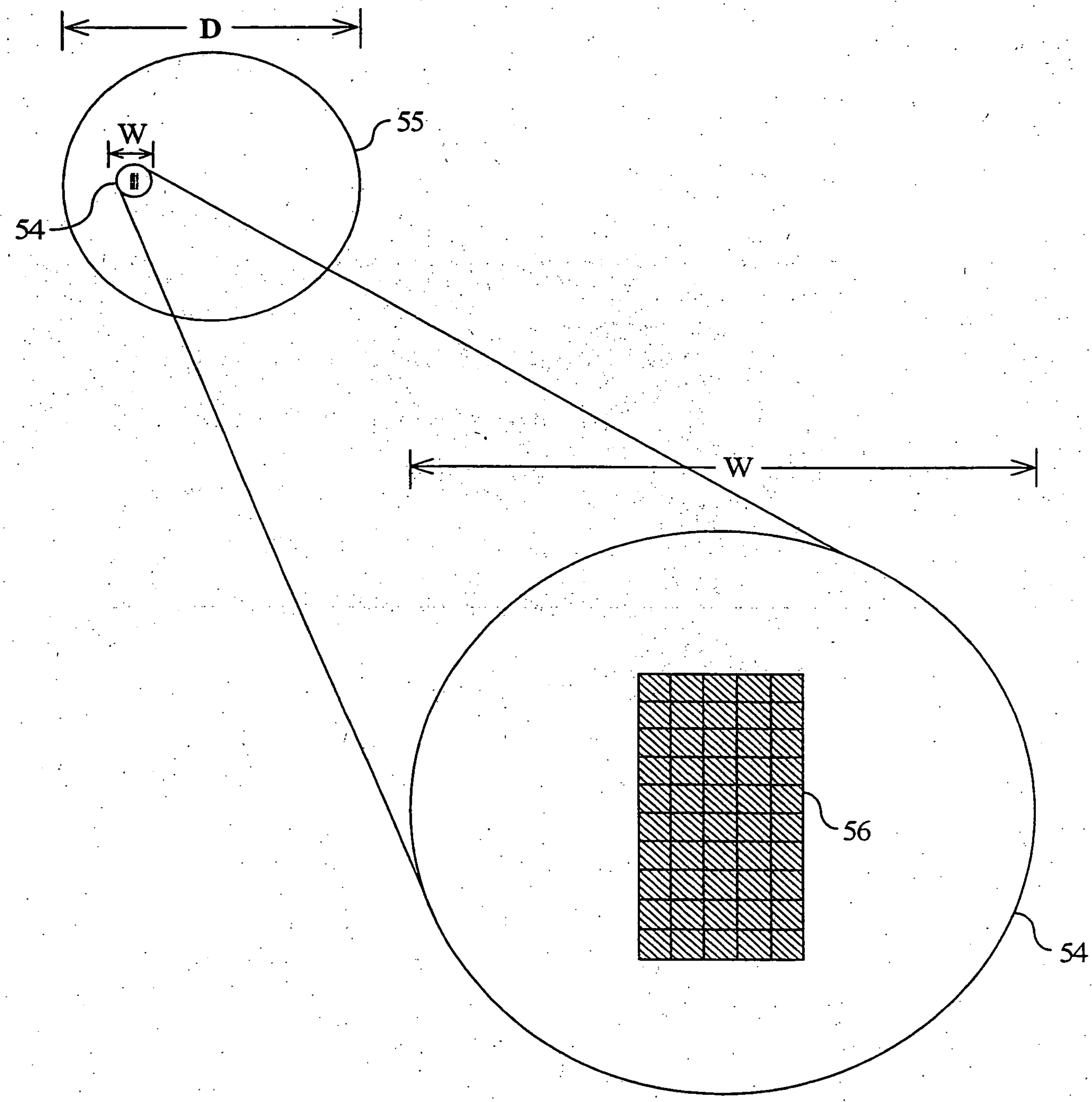

Figure 5

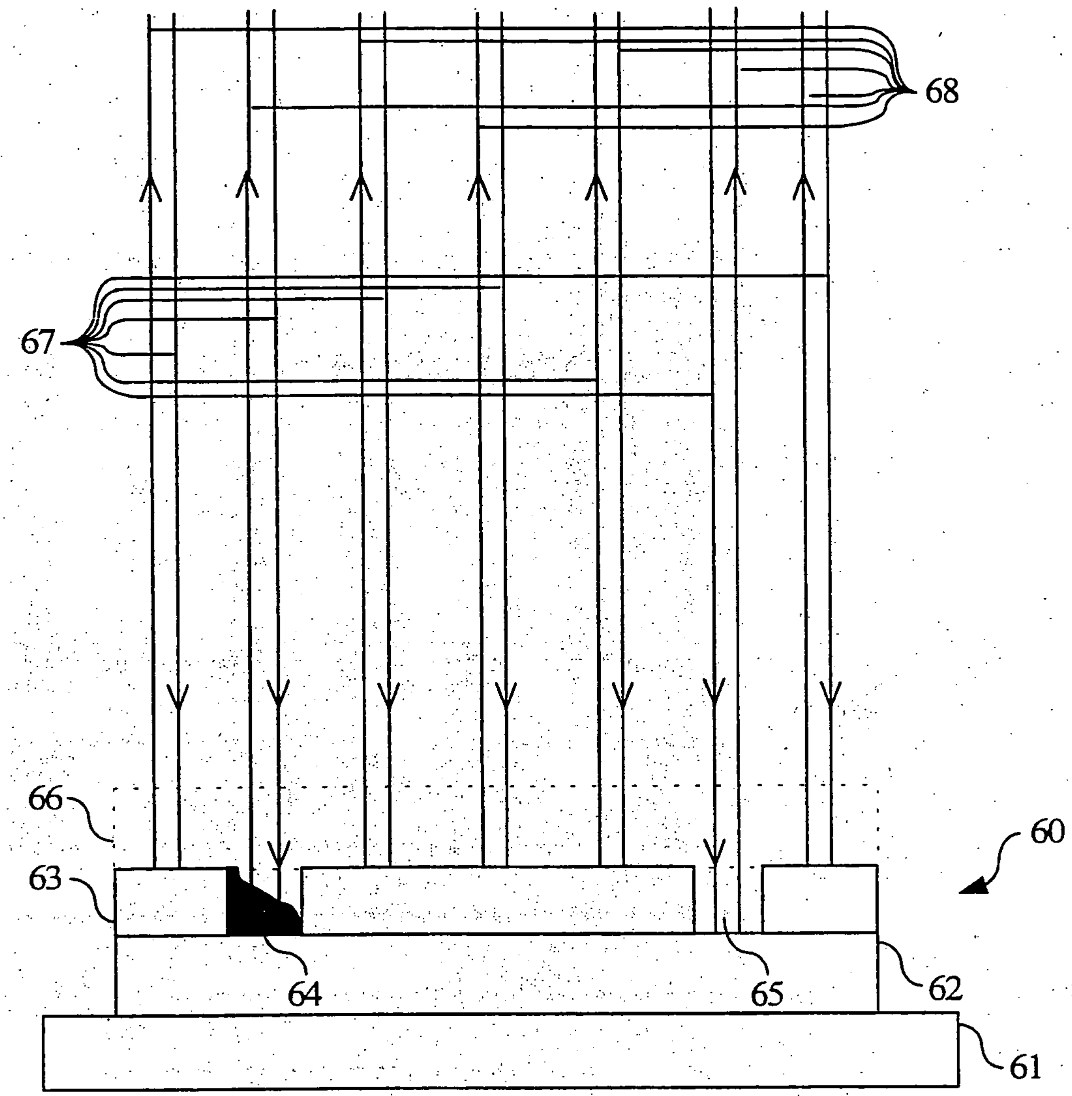

Figure 6 (a)

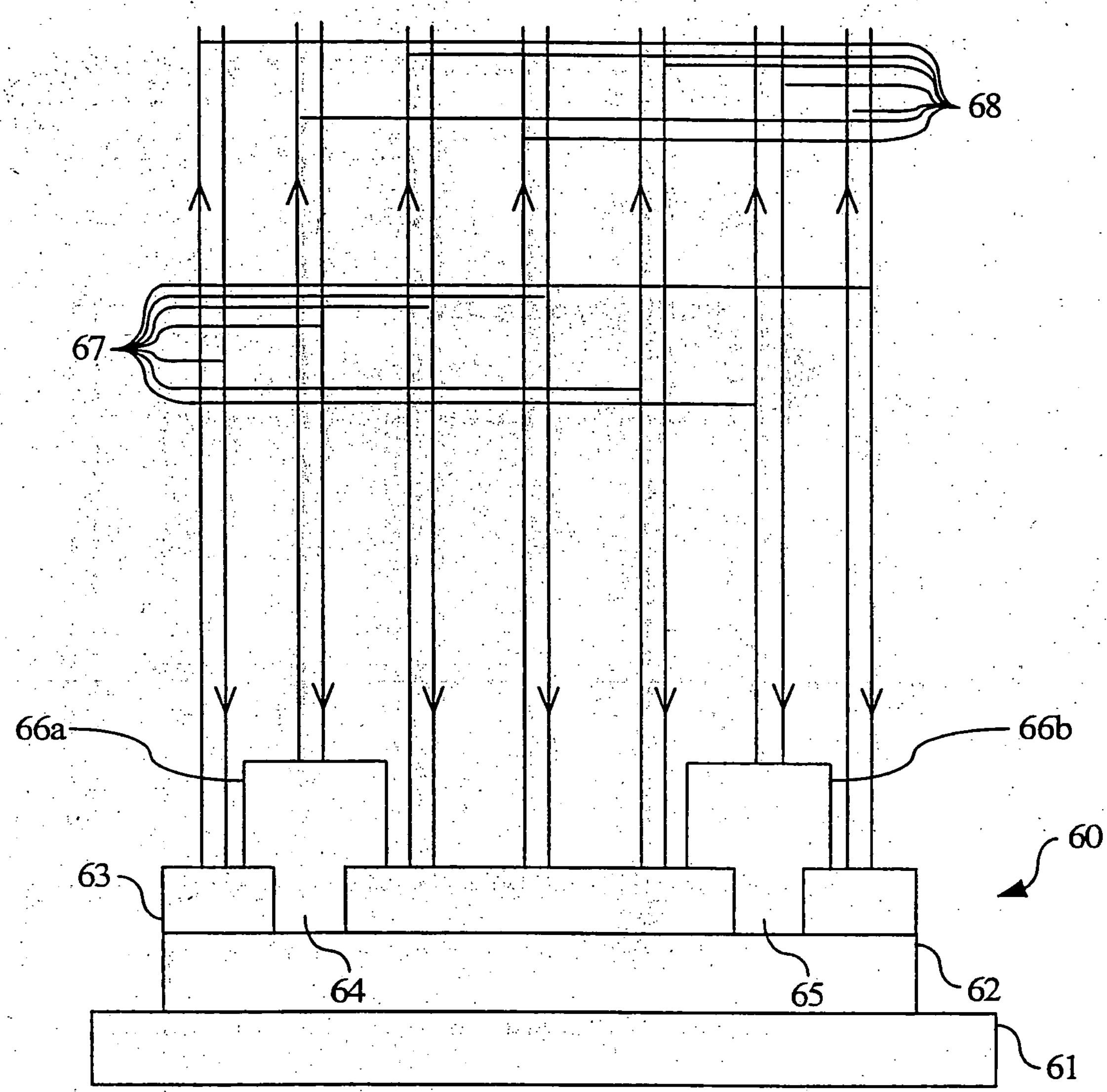

Figure 6 (b)

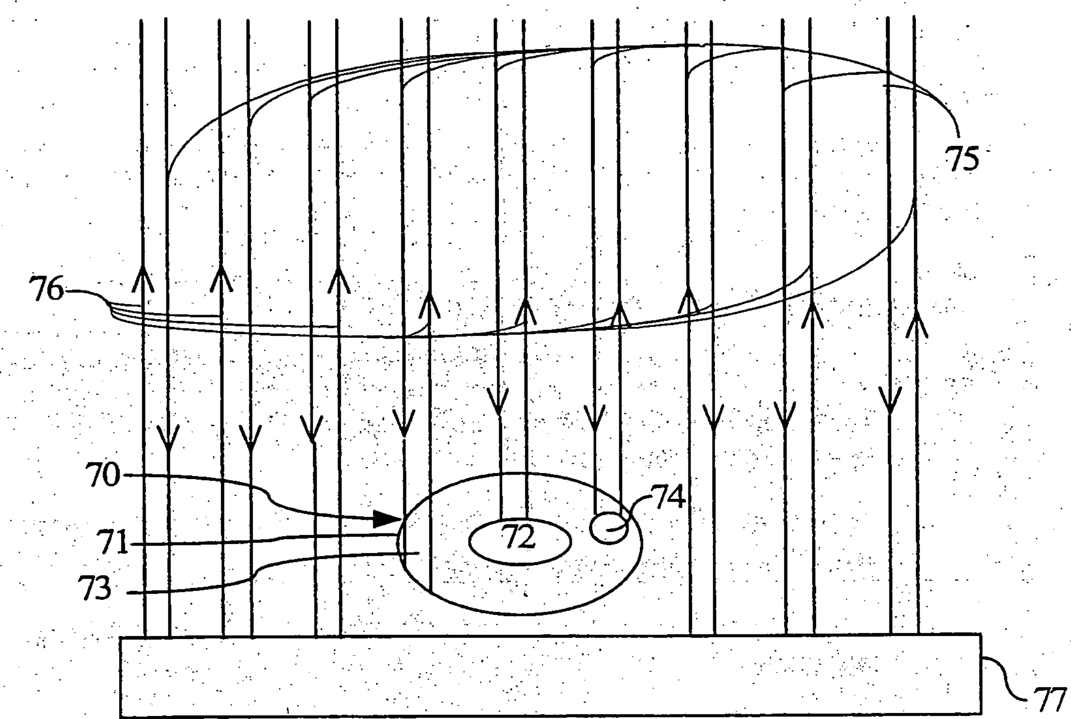

Figure 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/22706

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :HO1J 37/26
US CL : 250/310, 307
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 250/310, 307, 311

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

U.S. PTO APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,963823 A (OTTO ET. AL.) 16 OCTOBER 1990 (16.10.90). Note entire document.	1-69
A	US 4,954,705 A (BRUNNER ET. AL.) 04 SEPTEMBER 1990 (04.09.90). Note entire document.	1-69
A	US 4,933,552 A (LEE) 12 JUNE 1990 (12.06.90).Note entire document.	1-69

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 DECEMBER 1998	28 JAN 1999

Name and mailing address of the ISA/US	Authorized officer
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ENDEBLATT

DRUCKAUFTRAGS-ID: 820

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Druckauftrags-Id:	821
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⑲ BUNDESREPUBLIK DEUTSCHLAND

DEUTSCHES PATENTAMT

⑫ **Patentschrift**

⑪ **DE 37 22 518 C 1**

⑤① Int. Cl.⁴:
B 23 Q 23/00
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B 23 Q 17/22
G 01 B 21/00

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②① Aktenzeichen: P 37 22 518.9-14
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④③ Offenlegungstag: —
④⑤ Veröffentlichungstag der Patenterteilung: 26. 1. 89

Innerhalb von 3 Monaten nach Veröffentlichung der Erteilung kann Einspruch erhoben werden

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⑤⑥ Für die Beurteilung der Patentfähigkeit in Betracht gezogene Druckschriften:

DE-AS 12 18 251
CH 5 24 431

⑤④ Mit einer Temperaturausgleichseinrichtung versehene Meßeinrichtung für Werkzeugmaschinen

Bei einer aus einem Meßkopf und einem Referenz-Maßstab bestehenden Meßeinrichtung zur Direkterfassung von insbesondere linearen Werkstückmaßen zur Anwendung bei Werkzeugmaschinen für die spanende Formung von Werkstücken, wie z. B. Senkrechtdrehmaschinen, mit einem das Werkstück haltenden, relativ zum Werkstück linear verstellbaren Support und einem relativ zum Werkstück ortsfesten Support-Träger, ist zur Kompensation von durch Änderungen der Umgebungstemperatur bedingten Abweichungen zwischen der Werkzeugmaschine und dem Werkstück einerseits und der Meßeinrichtung andererseits letztere mit einer Temperaturausgleichseinheit gekoppelt. Die Temperaturausgleichseinheit ist durch einen die Arbeitstemperatur der Meßeinheit regelnden, an diesen angekoppelten Wärmeaustauscher realisiert.
Damit ist es möglich, durch Änderung der Umgebungstemperatur auftretende Differenzen zwischen den Maßverkörperungen am Meßkopf der Meßeinrichtung einerseits und an der Werkzeugmaschine bzw. am Werkstück andererseits direkt zu kompensieren, um jederzeit exakte und dem Justagezustand der Werkzeugmaschine entsprechende reproduzierbare Meßergebnisse zu erhalten.

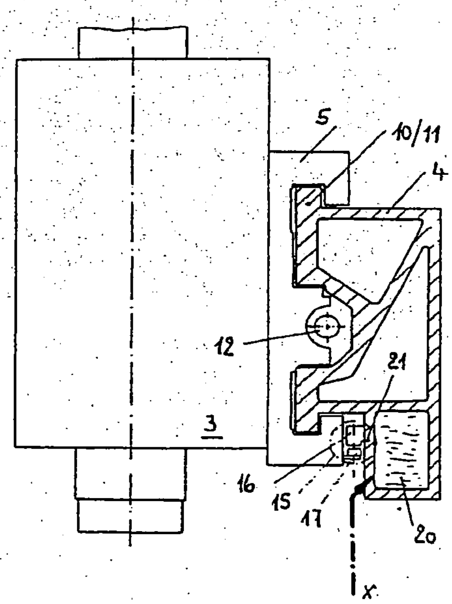

Fig. 2

DE 37 22 518 C 1

Patentansprüche

1. Aus einem Meßkopf und einem Referenz-Maßstab bestehende Meßeinrichtung zur Direkterfassung von insbesondere linearen Werkstückmaßen zur Anwendung bei Werkzeugmaschinen für die spanende Formung von Werkstücken, z. B. Senkrechtdrehmaschinen, mit einem das Werkzeug haltenden, relativ zum Werkstück linear verstellbaren Support und einem relativ zum Werkstück ortsfesten Support-Träger, wobei zur Kompensation von durch Änderungen der Umgebungstemperatur zwischen der Werkzeugmaschine und dem Werkstück einerseits und der Meßeinrichtung andererseits bedingten Meßfehlern die Meßeinrichtung mit einer Temperaturausgleichseinheit gekoppelt ist, die durch einen die Arbeitstemperatur der Meßeinrichtung regelnden, an diese angekoppelten Wärmetauscher realisiert ist, **dadurch gekennzeichnet,** daß der Wärmetauscher ein von einem Wärmeträgermedium, insbesondere Öl, durchströmter kanalähnlicher Hohlraum (20) des Support-Trägers (4) ist und

daß eine Wand dieses Hohlraums (20) Befestigungswand (21) für den Maßstab (16) der Meßeinrichtung (15) ist.

2. Aus einem Meßkopf und einem Referenz-Maßstab bestehende Meßeinrichtung zur Direkterfassung von insbesondere linearen Werkstückmaßen zur Anwendung bei Werkzeugmaschinen für die spanende Formung von Werkstücken, z. B. Senkrechtdrehmaschinen, mit einem das Werkzeug haltenden, relativ zum Werkstück linear verstellbaren Support und einem relativ zum Werkstück ortsfesten Support-Träger, wobei zur Kompensation von durch Änderungen der Umgebungstemperatur zwischen der Werkzeugmaschine und dem Werkstück einerseits und der Meßeinrichtung andererseits bedingten Meßfehlern die Meßeinrichtung mit einer Temperaturausgleichseinheit gekoppelt ist, die durch einen die Arbeitstemperatur der Meßeinrichtung regelnden, an diese angekoppelten Wärmetauscher realisiert ist, dadurch gekennzeichnet, daß der Wärmetauscher ein von einem Wärmeträgermedium, insbesondere Öl, durchströmtes Rohr (Vierkantrohr 25) ist, das thermisch mit dem Maßstab (16) der Meßeinrichtung (15) gekoppelt ist.

3. Meßeinrichtung nach Anspruch 2, dadurch gekennzeichnet, daß das Rohr (25) thermisch isoliert am Support-Träger (4) fixiert ist und daß am Übergang vom Rohr (25) zum Maßstab (16) der Meßeinrichtung (15) ein Streifen aus gut wärmeleitendem Metall eingelegt ist.

4. Meßeinrichtung nach einem der Ansprüche 1 bis 3, dadurch gekennzeichnet, daß am Übergang zwischen Maßstab (16) und Wärmetauscher (20 bzw. 25) ein Thermofühler eingesetzt ist.

Beschreibung

Die Erfindung bezieht sich auf eine aus einem Meßkopf und einem Referenz-Maßstab bestehende Meßeinrichtung zur Direkterfassung von insbesondere linearen Werkstückmaßen zur Anwendung bei Werkzeugmaschinen mit einer Temperaturausgleichseinheit zur Kompensation von durch Änderungen der Umgebungstemperatur bedingten Meßfehlern nach dem Oberbegriff des Patentanspruchs 1.

Meßeinrichtungen der gattungsgemäßen Art finden aufgrund ihrer Zuverlässigkeit und Meßgenauigkeit zunehmend Verwendung, und zwar vorzugsweise in Form digital arbeitender Längenmeßsysteme. Diese Längenmeßsysteme bestehen aus einem Referenz-Maßstab, einem Meßkopf und einem Detektor. Der Referenz-Maßstab dient dabei als eigentliches Maß- oder Abstandsnormal, längs dem der Meßkopf bewegt wird, um das jeweils aktuelle Abstandsmaß abzulesen bzw. abzutasten und an den Detektor abzugeben. Dieser interpoliert das vom Meßkopf erfaßte Signal und setzt dieses Signal in ein Meß- oder Kontrollsignal um, das dann entsprechend (digital) verarbeitet wird.

Es ist allgemein bekannt, daß jede Messung mit sogenannten Meßfehlern behaftet ist. Diese Meßfehler entstehen durch Unvollkommenheit der Meßeinrichtung an sich, durch Einwirkung, insbesondere Bedienungsfehler der Bedienungsperson und auch durch Einflüsse der Umgebung. Während die beiden erstgenannten Fehlerquellen im allgemeinen leicht erkennbar und damit leicht eliminierbar sind, haben die Einflüsse der Umgebung eine im allgemeinen nur schwer erfaßbare Ursache und sie sind demzufolge auch nur schwerlich eliminierbar. Dies gilt ganz besonders im Hinblick auf Störungen des sogenannten thermischen Gleichgewichts zwischen z. B. der Werkzeugmaschine und der Meßeinrichtung an dieser Werkzeugmaschine, und zwar insbesondere dann, wenn an dieser als in sich geschlossenes System zu betrachtenden Konfiguration sogenannte temperatursensible Werkstoffe beteiligt sind.

Bei der Inbetriebnahme einer Maschine werden die Bearbeitungsachsen der Werkzeugmaschine heutzutage zumeist mit Hilfe eines Laser-Interferometers vermessen und gegebenenfalls korrigiert.

Die damit hergestellte Genauigkeit gilt für die zum Zeitpunkt der Vermessung vorhandene Meßsystemtemperatur. Ändert sich im Laufe des nachfolgenden Betriebs diese Temperatur, so verändert sich auch die Länge des Meßsystems und die Genauigkeit des Gesamtsystems verschlechtert sich.

Es gibt prinzipiell zwei Einflußquellen für eine Temperaturveränderung:

Zum einen kann sich die Umgebungstemperatur ändern, und darüber hinaus kann sich auch die Maschinentemperatur ändern. Beide Einflüsse können auch kumulativ auftreten. Die Umgebungstemperatur wäre durch entsprechende Klimatisierung zu egalisieren, was jedoch eine unrealistische Forderung bedeutet.

Die Konstanthaltung der Maschinentemperatur bei unterschiedlichen Betriebsbedingungen ist demgegenüber einfacher zu realisieren.

Im Rahmen der sogenannten ökologischen Meßtechnik wird auch die rechnerische Berücksichtigung von Umwelteinflüssen angewandt. Dies erfordert jedoch umfangreiche Vorarbeiten, da letztlich eine Vielzahl von Meßreihen für jeweils spezifische Rahmenbedingungen ermittelt werden müssen. Diese Meßreihen stehen dann als Systemparameter zur Verfügung und erlauben eine Umrechnung akueller Meßergebnisse auf einen sogenannten Normalzustand.

Nach dem Stand der Technik (DE-AS 12 18 251 und CH-PS 5 24 431) sind grundsätzlich Werkzeugmaschinen bekannt, bei denen zur Konstanthaltung der Temperaturdifferenzen zwischen den einzelnen Maschinenteilen und damit zur Kompensation von temperaturbedingten Maßungenauigkeiten am Werkstück den Werkzeugmaschinen Wärmetauscher zugeordnet sind. Über das durch den Wärmetauscher fließende Wärmetau-

scher-Medium wird die jeweilige Temperatur am zugehörigen Maschinenteil beeinflußt.

Der apparative Aufwand ist hierbei sehr groß, da alle Maschinenteile, die die Maßgenauigkeit der Werkstükke beeinflussen, je für sich über einen eigenen Wärmetauscher-Kreislauf von einem Referenz-Maschinenteil ausgehend geregelt werden (DE-AS 12 18 251) oder alle Maschinenteile über einen zwar gemeinsamen, jedoch sehr komplexen Kreislauf mit unterschiedlichen Bohrungen und Zu- und Rückleitungen geregelt werden (CH-PS 5 24 431).

Ausgehend von diesem Stand der Technik besteht die der Erfindung zugrunde liegende Aufgabe darin, eine Meßeinrichtung der gattungsgemäßen Art zu schaffen, bei der ein Wärmetauscher für die Meßeinrichtung mit relativ geringem apparativem Aufwand und unter Ausnutzung der konstruktiven Gegebenheiten der Werkzeugmaschine in das Gesamtsystem integriert werden kann, und somit eine optimale thermische Kopplung zwischen dem Wärmetauscher und der Meßeinrichtung geschaffen wird.

Diese Aufgabe wird in Verbindung mit den Oberbegriffsmerkmalen erfindungsgemäß dadurch gelöst, daß der Wärmetauscher ein von einem Wärmeträgermedium, insbesondere Öl, durchströmter kanalähnlicher Hohlraum des Support-Trägers ist und daß eine Wand dieses Hohlraums Befestigungswand für den Maßstab der Meßeinrichtung ist (Anspruch 1), oder daß der Wärmetauscher ein von einem Wärmeträgermedium, insbesondere Öl, durchströmtes Rohr (Vierkantrohr) ist, das thermisch mit dem Maßstab der Meßeinrichtung gekoppelt ist (Anspruch 2).

Dank der erfindungsgemäßen Ausbildung können nach der Justage, und zwar z. B. aufgrund von Änderungen der Umgebungslufttemperatur, auftretende Differenzen zwischen den sogenannten Maßverkörperungen im Meßkopf der Meßeinrichtung einerseits und an der Werkzeugmaschine bzw. am Werkstück andererseits direkt kompensiert werden, um jederzeit exakte und reproduzierbare Meßergebnisse zu erhalten.

In der Praxis bewirken nämlich Änderungen der äußeren Einflußgrößen wie Umgebungslufttemperatur, Temperaturstrahlung aus der Umgebung und der Temperatur des Maschinenkörpers an der Befestigungsstelle des Meßkopfes der Meßeinrichtung auch Veränderungen der Eigentemperatur der Meßeinrichtung und damit derer Maßverkörperung im Verhältnis zum Justagezustand, d. h. zu den Meßbedingungen am Ende der Justierungsarbeiten, so daß das thermische Gleichgewicht des Gesamtsystems gestört ist. Mit der Erfindung wird diesen Veränderungen unmittelbar und in konstruktiv einfacher Weise Rechnung getragen, und zwar insofern, als temperaturbedingte Abweichungen zwischen der Meßeinrichtung an sich und der Werkzeugmaschine mit dem Werkstück kompensiert werden.

Weiterbildungen der Erfindung sind Gegenstand der Unteransprüche 3 und 4.

Die Erfindung wird im folgenden anhand von in der Zeichnung schematisch dargestellten Ausführungsbeispielen erläutert. Es zeigt

Fig. 1 eine Zweitständer-Karusseldrehmaschine als Anwendungsbeispiel für die Meßeinrichtung,

Fig. 2 ein erstes Ausführungsbeispiel der Realisierung der Temperaturausgleichseinrichtung,

Fig. 3 ein zweites Ausführungsbeispiel der Realisierung der Temperaturausgleichseinrichtung,

Fig. 4 die Temperaturausgleichseinrichtung gemäß dem Ausführungsbeispiel nach **Fig.** 3 im Detail.

In **Fig.** 1 ist eine Senkrecht- (bzw. Karussel-) Drehmaschine dargestellt. Hierbei handelt es sich um eine Werkzeugmaschine zur spanabhebenden Bearbeitung von meist größeren scheiben- oder ringförmigen Werkstücken **1**. Diese werden auf einer horizontal angeordneten Planscheibe **2** justiert und mittels (u. U. mehrerer) sogenannter Drehmeißel **3** bearbeitet, die an Werkzeugträgern (Support) **5**, die wiederum an einem als Support-Träger **4** ausgebildeten Querbalken angeordnet sind, fixiert sind. Diese Supporte **5** und mit ihnen die Drehmeißel **3** können mittels einer Programmsteuerung positioniert (und so lange nachgestellt) werden, bis das Werkstück **1** die gewünschte (programmierte) Form hat.

Die Positioniergenauigkeit der Drehmeißel bestimmt letztlich die Meßgenauigkeit des fertigen Werkstücks. Dieser Positioniergenauigkeit muß somit erhöhtes Augenmerk zugewandt werden, was bezogen auf die vorliegende Erfindung bedeutet, daß temperaturbedingte Differenzen zwischen der Drehmaschine mit dem Werkstück einerseits und der (Weg-) Meßeinrichtung für die Supportbewegung andererseits vermieden werden müssen.

Fig. 2 zeigt einen Ausschnitt der Senkrecht-Drehmaschine nach **Fig.** 1, und zwar einen Ausschnitt entsprechend einer Seitenansicht auf diese Werkzeugmaschine.

Der Support-Träger **4** (Querbalken) ist geschnitten dargestellt. Er ist während der Bearbeitung eines Werkstücks ortsfest am Ständer bzw. an den Ständern der Karusseldrehmaschine fixiert. Der Support-Träger **4** hat einen etwa rechteckigen Querschnitt und dient als Führungsschlitten für den Support **5**. Dieser Support **5** und der Support-Träger **4** weisen ein nach Art einer Nut-/Feder-Verbindung **10/11** zueinander komplementär ausgebildetes Paar von Führungsnuten am Support-Träger **4** und zwei in diese Führungsnuten eingreifende Führungsschienen am Support **5** auf. Dieser kann somit z. B. mittels eines Spindeltriebs oder eines Schneckentriebs **12** (senkrecht zur Zeichenebene) längs des Support-Trägers **4** verfahren bzw. positioniert werden. Mit dem Support **5** ist der Drehmeißel **3** fest verbunden, so daß mit der Positionierung des Supports **5** auch der Drehmeißel **3** positioniert wird und bestimmungsgemäß das Werkstück spanabhebend geformt werden kann.

Wie erwähnt, wird der Support **5** mit dem Drehmeißel **3** mittels eines Linearantriebs längs der durch die genannte Nut-/Feder-Verbindung **10/11** realisierten Führung bewegt. Zur Messung der jeweiligen Relativbewegung zwischen Support-Träger **4** und Support **5**, d. h. zur Messung der zurückgelegten Wegstrecke und damit des Vorschubs des Drehmeißels bzw. zur Messung der Abmessungen des Werkstücks ist in einem Bereich zwischen Support **5** und Support-Träger **4** eine berührungslos arbeitende Meßeinrichtung **15** eingefügt, die aus einem fest mit dem Support-Träger **4** verbundenen Referenz-Maßstab **16** und einem am Support **5** selbst angebrachten Meßkopf **17** besteht. Der Meßkopf **17** und der Referenz-Maßstab **16** liegen dabei einander gegenüber, so daß über den Meßkopf **17** der Referenz-Maßstab **16** "abgelesen" werden kann.

Der Referenz-Maßstab **16** kann z. B. ein Stab aus magnetisierbarem Werkstoff sein, auf den eine gleichmäßige Teilung von z. B. 0,2 mm aufmagnetisiert ist. Mit der Relativbewegung zwischen dem Meßkopf **17** und diesem Maßstab **16** kann dann über die Sinus-Charakteristiken der Induktiv-Widerstandsänderung die genannte Teilung aufgenommen und in ein elektrisches Signal umgewandelt werden. Die Meßgenauigkeit beträgt dabei 0,001 mm, und es ist leicht einzusehen, daß schon

geringe temperaturbedingte Abweichungen zwischen den Teilen der Meßeinrichtung und der Werkzeugmaschine bzw. dem Werkstück diese Meßgenauigkeit beeinträchtigen können.

Konstruktiv betrachtet ist der Referenz-Maßstab 16 eine längs des Support-Trägers 4 angeordnete "Meßlatte", relativ zu der der Meßkopf 17 bewegt wird; der Meßkopf 17 "liest" die "Maßskala" vom Referenz-Maßstab 16 ab und gibt sie zur Weiterverarbeitung an einen Detektor und eine (digitale) Weiterverarbeitungseinheit ab. Der Meßkopf 17 ist mit dem Support 5 fest verbunden und relativ zum Referenz-Maßstab 16 so justiert, daß beide Elemente der Meßeinrichtung 15 funktionell aufeinander abgestimmt sind.

Wie eingangs erwähnt, bewirken Änderungen der Umgebungstemperatur unterschiedliche Änderungen an der Maschine und dem Werkstück einerseits und an der Meßeinrichtung andererseits und damit Differenzen im Meßsignal und in der Meßgenauigkeit.

Zur Kompensation derartiger Meßfehler ist die Meßeinrichtung 15 thermisch an eine Temperaturausgleicheinheit angekoppelt, die Abweichungen des thermischen Gleichgewichts zwischen der Maschine mit dem Werkstück einerseits und der Meßeinrichtung andererseits ausgleicht. Im Ausführungsbeispiel nach **Fig. 2** ist der Maßstab 16 an einem längs des Support-Trägers 4 vorgesehenen kanalähnlichen Hohlraum 20 befestigt, der von einem Wärmeträgermedium, insbesondere Öl, durchströmt wird. Dieser Hohlraum 20 ist als rechteckiger Kanal ein Teil des Support-Trägers 4; die eine Wand dieses Kanals ist dabei Befestigungswand 21 für den Maßstab 16 und liegt dem Ansatz des Supports 5 mit dem Meßkopf 17 gegenüber.

In der Praxis ist die Wirkungsweise dieses Hohlraums 20 bzw. des Wärmeübertragungsmediums so, daß dessen Wärmeinhalt, d. h. Temperatur, so gewählt bzw. so geregelt *(X)* wird, daß die vorgenannten Differenzen zwischen Maschine und Meßeinrichtung 15 kompensiert werden. Zu diesem Zweck ist mit der Drehmaschine und dem Werkstück ein Thermofühler verbunden, der bei Änderung der Umgebungstemperatur die Temperatur des Wärmeübertragungsmediums entsprechend einregelt. Damit ist — bezogen auf das Gesamtsystem Drehmaschine — die Umgebungstemperatur der Meßeinrichtung praktisch verzögerungsfrei als wahre, dem Gesamtsystem entsprechende Umgebungstemperatur simulierbar.

In **Fig. 3** ist ein zweites Ausführungsbeispiel der Temperaturausgleichseinheit dargestellt.

Die Grundkonfiguration Support-Träger 4, Support 5 und Drehmeißel 3 entspricht der nach **Fig. 2**. Auch hier sind Support-Träger 4 und Support 5 über eine Nut-/Feder-Verbindung 10/11 miteinander verbunden, so daß der Support 5 mit dem Drehmeißel 3 längs des Support-Trägers 4 verfahren werden kann.

Die berührungslos arbeitende Meßeinrichtung 15 besteht wiederum aus einem Maßstab 16, der an einer am Support-Träger 4 vorgesehenen Befestigungskonsole 22 befestigt ist, und aus einem am Support 5 fixierten Meßkopf 17 (oder Reflexionsschiene). Bis hierher entsprechen sich in etwa die Konstruktionen gemäß **Fig. 2** und **Fig. 3**.

Bei dem Ausführungsbeispiel gemäß **Fig. 3** ist die Temperaturausgleichseinheit jedoch ein vom Wärmeträgermedium, z. B. Öl, durchströmtes Vierkant-Rohr 25, das in den Freiraum zwischen Befestigungskonsole 22, Support-Träger 4 und Maßstab 16 eingefügt ist. Analog zur Beschreibung zu **Fig. 2** wird das durch dieses Vierkantrohr 25 strömende Wärmeträgermedium den Umgebungstemperaturen an der Drehmaschine und am Werkstück entsprechend temperiert, so daß an der Meßeinrichtung 15 stets äquivalente Meßbedingungen vorliegen (Pfeil *Y*).

Die Details des Ausführungsbeispiels nach **Fig. 3** werden anhand von **Fig. 4** erläutert.

Der Maßstab 16 ist an der Befestigungskonsole 22 des Support-Trägers 4 fixiert, und zwar in einem gewissen Abstand zu dessen Unterseite. In diesen einseitig offenen rechteckigen Freiraum ist das Vierkantrohr 25 eingesetzt, und zwar thermisch isoliert gegenüber dem Support-Träger 4 und dessen abstehender Befestigungskonsole 22. Gegen die Befestigungskonsole 22 ist das Vierkantrohr 25 mittels eines Kunststoffstreifens 30 isoliert; gegen den Support-Träger 4 selbst liegt das Vierkantrohr 25 an einem durch ein Klemmstück 31 vorgespanntes Moosgummiband 32 an, wobei dieses Klemmstück 31 zusätzlich zum Einklemmen bzw. Fixieren des Vierkantrohres 25 an der Befestigungskonsole 22 dient. Damit liegt das Vierkantrohr 25 fest im Freiraum zwischen Maßstab 16 und Support-Träger 4. Zwischen Vierkantrohr 25 und Maßstab 16 ist zur Verbesserung des Wärmeübergangs ein Streifen 33 aus gut wärmeleitendem Metall, z. B. ein Kupferstreifen, eingelegt, der zusätzlich noch beidseitig mit Wärmeleitpaste beschichtet sein kann.

Darüber hinaus kann zwischen dem Vierkantrohr 25 bzw. den wärmeleitenden Streifen 33 und dem Maßstab 16 noch ein Thermofühler 34 eingesetzt werden, der zur Messung der Arbeitstemperatur der Meßeinrichtung 15 dient.

Die Art und Weise des Einbaus des Vierkantrohrs 25 ist selbstverständlich von den spezifischen konstruktiven Bedingungen im Hinblick auf den Meßkopf 17 und den Support-Träger 4 abhängig. Global betrachtet kommt es bei der vorliegenden Erfindung darauf an, am Meßkopf 17 bzw. an der Meßeinrichtung 15 möglichst verzögerungsfrei eine Arbeitstemperatur einzustellen, die der Umgebungstemperatur der übrigen Teile des Gesamtsystems entspricht, und zwar ohne daß klimatisierte Räume oder aufwendige Vorarbeiten zur Gewinnung von Korrekturfaktoren erforderlich sind.

Die Erfindung wurde vorstehend am Beispiel einer Karusselldrehmaschine offenbart. Selbstverständlich ist die Erfindung jedoch nicht auf dieses Anwendungsgebiet beschränkt, sondern wird immer dann von großem Nutzen sein, wenn Abweichungen der Meßergebnisse aufgrund von Unterschieden der Umgebungstemperaturen an der Maschine einerseits und an der Meßeinrichtung andererseits kompensiert werden müssen.

Hierzu 2 Blatt Zeichnungen

Nummer: 37 22 518
Int. Cl.[4]: B 23 Q 23/00
Veröffentlichungstag: 26. Januar 1989

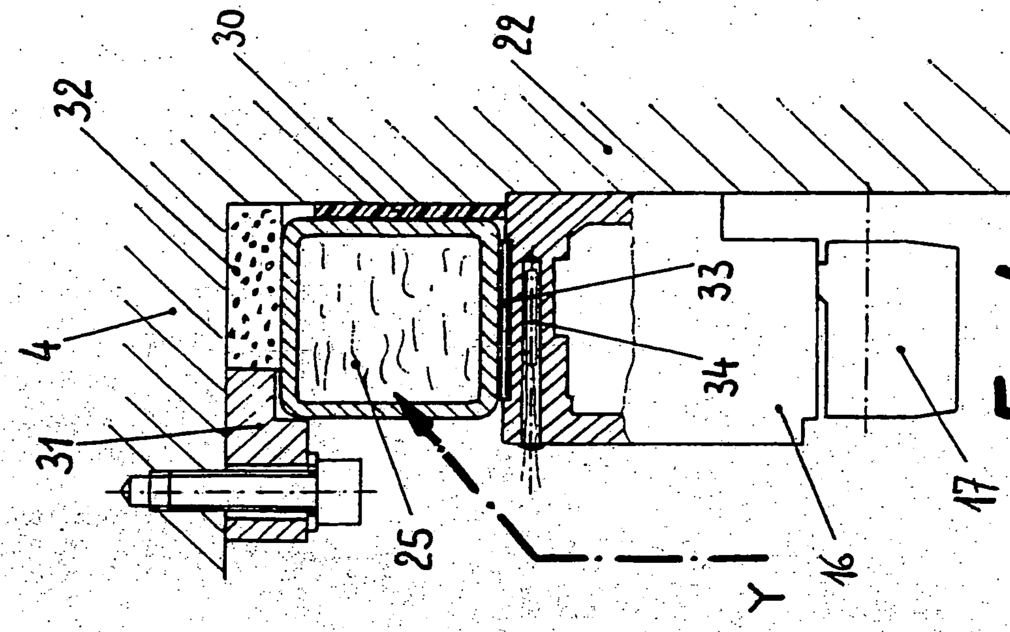

Fig 4

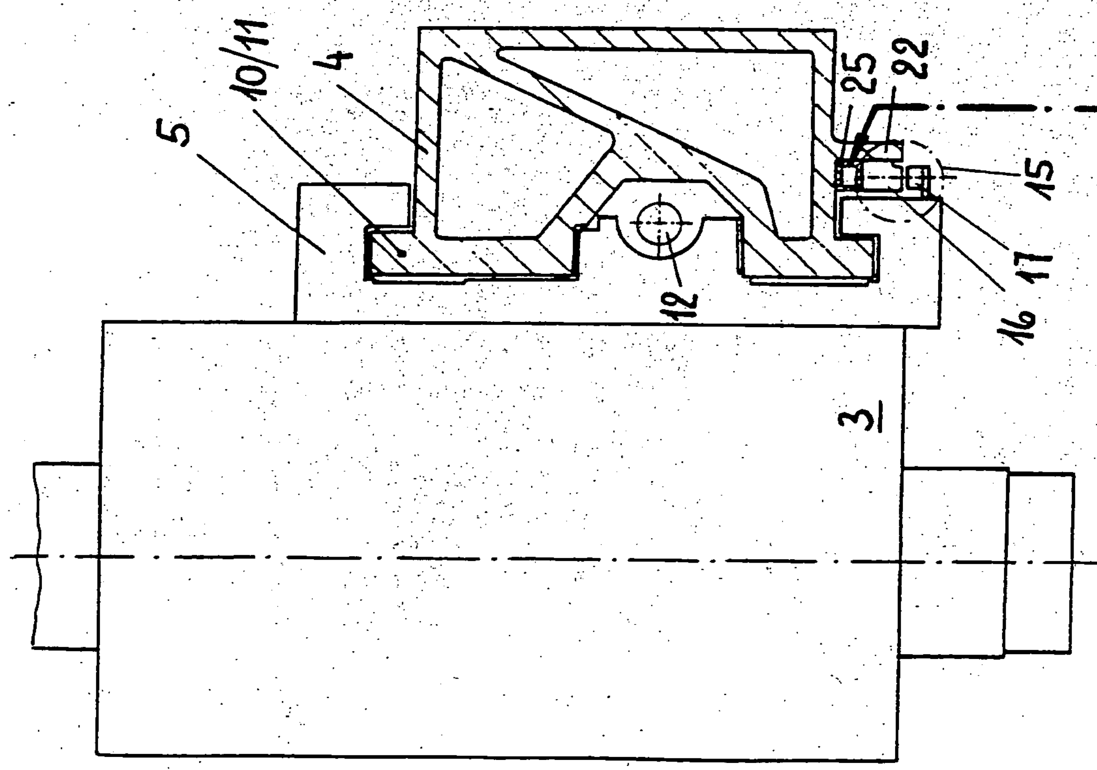

Fig. 3

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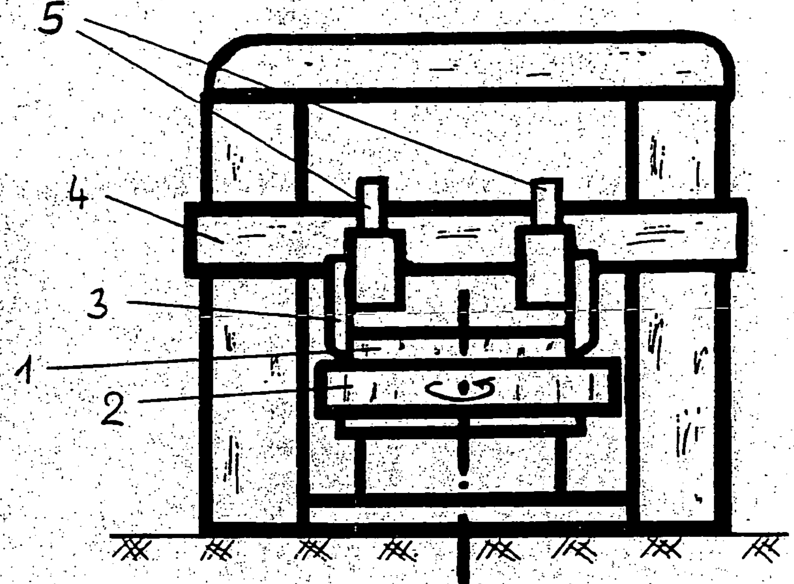
Fig. 1



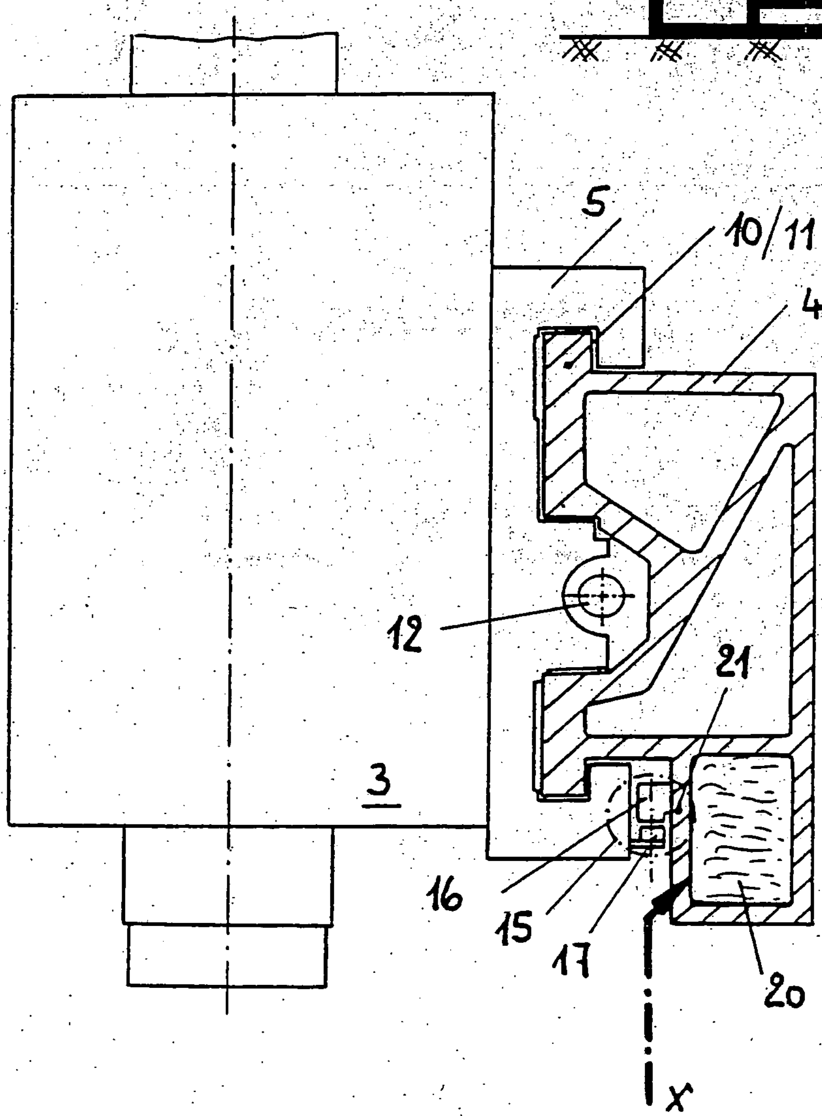


Fig. 2

ENDEBLATT

DRUCKAUFTRAGS-ID: 821

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Drucker: gdHO5320
Job Beginn: 06.06.2003 15:28
Job Ende: 06.06.2003 15:28